ON A POSSIBLE CLASSIFICATION OF ELEMENTARY PARTICLES IN THE QUARK MODEL

Ya. I. Azimov, V. V. Anisovich, A. A. Ansel'm, G. S. Danilov, and I. T. Dyatlov
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
Submitted 3 June 1965

The distribution of elementary particles and resonances in the lower multiplets is in good agreement with the quark model [1-2]. There are several possibilities for describing the higher multiplets in this model. For baryons, for example, one possibility is to examine the excited states of a three-quark system. The character of such excitations can differ greatly even in the nonrelativistic model. In the lower multiplets the total orbital momentum is a good quantum number (the entire baryon 56-plet can be satisfactorily described by a single antisymmetrical coordinate function $\Psi_0(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3)$ corresponding to zero total orbital momentum). We can therefore assume that the higher multiplets are also described by wave functions of the type $\Psi_L(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3)\chi_\alpha$, where Ψ_L corresponds to the total orbital momentum of the quarks, equal to L, and the charge-spin functions χ_α are the same as for the lower multiplets (octet and decuplet). The constructed quark states are then characterized by a total orbital momentum L and total spin S; the existing degeneracy in the total angular momentum J is lifted by the spin-orbit interaction $\alpha_L(\mathbf{L}\cdot\mathbf{S})$, where α_L depends only on L. The degeneracy in the total spin is lifted by the spin-spin interaction $\beta_L S(S + 1)$.

We assume further that the mass splitting within each multiplet is determined essentially by the mass increase of the third quark [2,3]. This model is close, with respect to the meson resonances, to the scheme described in [4], but the concrete classification of the resonances is different, for we are using here the idea of increased third-quark mass. When $L > 0$ the parity of the three-quark state is not determined uniquely by the value of L. We shall show below that agreement with the experimental data is possible if it is assumed that the parity is $(-1)^L$. We accept this as an empirical fact.

When L = 1 and S = 1/2, two octets are possible, with $J = 3/2^-$ and $J = 1/2^-$; these are excited states of the octet $1/2^+$ (see the Table). The mass difference of N_{1518}, Σ_{1660}, and Ξ_{1810} is 150 MeV, i.e., it agrees with the concept of simple mass increase of the third quark. The noticeable deviation of the Λ_{1519} mass may be due to the fact that in the state with L = 1 a greater contribution is made by the potential interactions, which are analogous to those considered in [5] but do not make up an octet component. The only known particle that may be included in the $1/2^-$ octet is the threshold resonance $(\Lambda\eta)_{1660}$ (inclusion of the Λ_{1405} resonance in this octet calls for the existence of the resonances N_{1400}, Σ_{1550}, and Ξ_{1700}, the failure of experimental detection of which is difficult to explain; difficulties arise also in the investigation of the decuplet). The value of α_L with L = 1 can be determined from the mass difference of Λ_{1660} and Λ_{1519}. This makes it possible to predict the masses of the remaining resonance of the $1/2^-$ octet (the solid underscores in the Table identify resonances whose appearance is masked by other known resonances). In decuplets with L = 1, only the resonances Δ_{1650} [6] and Σ_{1765} are known. The masses of the remaining resonances can be found by assuming an increase in the mass of the third quark and using the value of α_L obtained from a consideration of the octet with L = 1.

Let us consider finally the state of three quarks with L = 2, when the octets $5/2^+$ and $3/2^+$ and the decuplets $7/2^+$, $5/2^+$, $3/2^+$, and $1/2^+$ are possible. It is natural to ascribe to the $5/2^+$ octet the resonances N_{1688} and Λ_{1815}, and it is probable that the resonance Δ_{1924} enters in the $7/2^+$ decuplet. There are no experimental data whatever from which to determine the masses of the particles in the remaining multiplets with L = 2.

	L	J^P	S = 1/2	L	J^P	S = 3/2
Baryons	0	$1/2^+$	N_{940} Λ_{1115} Σ_{1190} Ξ_{1320}	0	$3/2^+$	Δ_{1236} Σ_{1382} Ξ_{1529} Ω_{1675}
	1	$3/2^-$	N_{1518} Λ_{1519} Σ_{1660} Ξ_{1810}	1	$5/2^-$	Δ_{1650} Σ_{1765} Ξ_{1930} Ω_{2100}
					$3/2^-$	Δ_{1885} Σ_{2000} Ξ_{2165} Ω_{2335}
		$1/2^-$	N_{1660} Λ_{1660} Σ_{1800} Ξ_{1950}		$1/2^-$	Δ_{2025} Σ_{2140} Ξ_{2300} Ω_{2475}
	2	$5/2^+$	N_{1688} Λ_{1815} Σ_{1830} Ξ_{1980} ……	2	$7/2^+$	Δ_{1924} Σ_{2040} Ξ_{2200} Ω_{2375} ….
	L, G	J^P	S = 0	L, G	J^P	S = 1
Mesons	0, $G=(-1)^T$	0^-	π_{140} K_{495} η_{549}	0, $G=(-1)^{T+1}$	1^-	ρ_{763} K^*_{890} ω_{783} φ_{1020}
	1, $G=(-1)^{T+1}$	1^+	B_{1216} K_{1360} η_{1400}	1, $G=(-1)^T$	2^+	$A_2(1310)$ K^*_{1430} f_{1250} φ_{1600}
					1^+	$A_1(1080)$ C_{1215} ω_{1100} E_{1415}
					0^+	ρ_{970} K^*_{1100} ω_{1000} φ_{1300}

Note. The experimental data were taken from material presented at the 12th Conference on High-energy Physics (Dubna, 1964) and from the paper by G. Goldhaber [8].

A similar classification can be formulated also for mesons. In this case the parity and G-parity of the quark-antiquark system are determined uniquely: $P = (-1)^{L+1}$, $G = (-1)^{L+S+1}$. A possible distribution of the known meson resonances over the multiplets is proposed in the Table. The masses of the missing particles in all multiplets, except 0^+, are estimated from the mass increase of the third quark. The masses of 0^+ resonances were obtained under the assumption that the splitting is due to the $\alpha_L(\underset{\sim}{L}\cdot\underset{\sim}{S})$ interaction. We present the main types of decays for the unobserved meson resonances:

$$K_{1360} \to K\rho,\ K^*\pi;\quad \eta_{1400} \to \pi\rho,\ K^*\bar{K};\quad \varphi_{1600} \to K\bar{K};\quad \omega_{1100} \to \pi\pi\eta,\ \pi\pi\rho,\ 4\pi;$$

$$\rho_{970} \to \pi\eta;\quad K^*_{1100} \to \pi K;\quad \omega_{1000} \to \pi\pi;\quad \varphi_{1300} \to K\bar{K}$$

The possible reason for not observing these resonances in experiments is that the resonances with large L are less likely to be created and, in addition, for a specified L the states with large J have a greater statistical weight.

Many of the observed meson resonances can be interpreted only as states of a system comprising several quarks and antiquarks (for example, resonances with T = 3/2 or with Y = 2). It is possible that κ_{725} is such a resonance.

In conclusion we wish to note that, in our opinion, there are facts that fit the framework of the simple model, according to which the elementary particles consist of nonrelativistic quarks, namely - the connection between the mass differences in various meson and baryon multiplets, and the equality of the magnetic moments of the proton and of the $\omega \rightarrow \pi + \gamma$ transition [7]. From the point of view of such a model, the particle classification presented above is perfectly probable, whereas the predicted mass values are, of course, estimates. The main feature of the scheme described is that it includes almost all presently known resonances.

The authors thank V. M. Shekhter for useful discussions.

[1] M. Gell-Mann, Phys. Lett. 8, 214 (1964).
[2] L. Zweig, CERN Preprint 8419/TH, 412, 1964.
[3] G. Borchi and R. Gatto, Phys. Lett. 14, 352 (1965).
[4] Bogolyubov, Struminskii, and Tavkhelidze, JINR Preprint D-1968.
[5] P. Carruthers and H. Bethe, Phys. Rev. Lett. 7, 536 (1960); B. Moyer, Revs. Mod. Phys. 33, 367 (1961); J. A. Holland et al., Phys. Rev. Lett. 10, 27 (1963).
[6] Azimov, Anisovich, Ansel'm, Danilov, and Dyatlov, JETP Letters 1, No. 2, 50 (1965), transl. p. 72.
[7] G. Goldhaber, Preprint, UCRL - 11971, 1965.

ROTATION OF SUPERDENSE CONFIGURATIONS

V. Ts. Gurovich and O. Kh. Guseinov
Submitted 3 June 1965

Statistical superdense configurations with average density $\rho_{av} > 10^{12}$ g/cm^3 have a limiting mass $M = 1.55M_\odot$ at a radius $R = 8.92$ km [1]. It is of interest to consider the influence of rotation on the parameters of such stars.

As is well known, in ordinary stars the centrifugal force can balance the gravitational force, for if the momentum is conserved the centrifugal force increases like $1/r^3$, while the gravitational force is proportional to $1/r^2$. At very large rotational velocities ($v \sim c$), however, the centrifugal force increases already like $1/r$, against $1/r^2$ for gravitation. This example illustrates the extent to which the situation changes at large rotational velocities (general-relativity effects will be discussed below); it follows therefore that rotation has little influence on the parameters of neutron stars.

Calculation of a rotating configuration on the basis of Newton's theory is rather cumbersome, and in Einstein's theory the difficulties increase by many times. We therefore estimate the configuration parameters for the following simplified model: We assume the star rotation to be such that the deviation from sphericity of the hyperon core, which has 0.93 - 0.97 of the mass of the entire configuration, can be neglected. The angular momentum of the star M should then be smaller than MR_gc (R_g is the gravitational radius of the configuration), which is of the order of the solar momentum. Under this assumption the shell of the hyperon star rotates in fact in an external gravitational field produced by a spherically-symmetrical rotating core.